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Introduction

Waste is produced in large quantities in cattle feedlots, and this is a potential environmental pollutant. Recycling of feedlot waste as livestock feed has been investigated extensively as one means of lowering the disposable waste load. Refeeding fresh manure will only partially alleviate waste disposal problems. In one study, only about one-half of the manure collected daily could be refed, and the remainder was discarded.

Currently, there is increased interest in the development of a microbial process for recycling and utilizing feedlot wastes. Commercial digestors are in operation. In some of these systems, the potential exists for capturing methane as a product of fermentation and recovering a biomass product which has potential feed value. Because of high capital costs associated with the equipment, labor, etc., necessary for the fermentation process, preliminary economic analyses indicate that, for the fermentation system to be profitable at moderate feedlot sizes, the operation must show a reasonable return for the feeding value of the fermentor effluent biomass. Based on its nutrient content (particularly total nitrogen, amino acids, and some essential minerals), fermentor effluent should be a good dietary supplement for ruminant livestock.

Thermophilic (high temperature) anaerobic fermentation of livestock manures has several advantages that make it attractive for more detailed investigation. Thermophilic fermentation has the potential for higher methane production rates, and minimizes the potential for disease transmission compared with mesophilic (ambient temperature) systems. In addition, fermentation systems have the potential of improving the nutritive value of the nitrogen present in the waste.

Data in this paper describe the chemical composition of the cattle wastes and different fractions of effluent obtained from the anaerobic fermentor and the *in vitro* digestibility of these fractions. *In vivo* experiments in cattle were also used to evaluate the potential feed value of the fermentor biomass using short-term (21 to 35 day) digestion and metabolism studies.

Procedure

The MARC pilot scale thermophilic, anaerobic fermentation system was used to produce the product used in these experiments. Material used in our nutritional studies was obtained as follows: fresh manure was gathered daily from steers housed in a partially roofed structure with concrete-floored pens and fed a standard diet composed of approximately 88.5% corn, 2.5% soybean meal, and 9% corn silage on a dry matter basis. Antibiotics and other feed additives were not fed to these steers. The manure was transported to the pilot plant by a small front-end loader and dumped into the slurry tank. Water was added and the slurry mixed for about 2 hr. Samples were taken for dry matter (DM) and organic matter (OM) determinations. Based on DM and OM concentrations, a given amount of slurry was pumped into a weigh tank, and water was added to dilute the slurry to a specified DM concentration. Slurry in the weigh tank (referred to as fermentor influent, FI) was mixed, while slurry was pumped through a heat exchanger loop and into the fermentor with a working volume of 180.1 cu ft. Before adding fresh slurry into the fermentor, a specified volume of fermented effluent (FE), corresponding to the desired retention time, was removed. The FE was either mixed directly with other feed ingredients for livestock feeding trials or centrifuged. The solids [referred to as dried centrifuged biomass (DCB)] were recovered and dried in a forced-air oven at 158°F.

Experiment 1. A total of 30 crossbred steers (640 lb avg liveweight) were grouped by wt and assigned at random to one of three dietary treatment groups (10/group; control, negative control, and FE; Table 1). All steers were adjusted to the control (C) diet over a 3-wk period. During this time, steers were trained to use individual feeding stalls with electronic headgates. Water was added to the positive and the negative control diets to provide a diet DM content that was approximately similar for the three treatments. On the first three days, only 25% of the designated amount of water or FE was added to the dry diet. The amount of FE or water was increased by 25% every three days so that, by day 10, steers were receiving the designated amount of FE or water. After 21 days on the respective diets, steers were weighed on two consecutive days; thereafter, weights were taken every 21 days for a total of eight periods (168 days).

At the conclusion of the experiment, a final wt was obtained on two consecutive days, and steers were transported to a commercial plant for slaughter the next day. Hot carcass weights were obtained, and other carcass data were obtained after a 24-hr chill. Carcasses were evaluated for marbling, grade, and percentage of kidney, pelvic, and heart fat. Longissimus area was traced and external fat thickness measured at the 12th rib.

Experiment 2. Eighty yearling crossbred heifer calves were assigned by wt and breed to one of the four dietary treatments outlined in Table 1. Eight heifers/treatment were fed using individual feeding stalls with electronic headgates. An additional 12 animals per treatment were housed and fed in groups of 4 animals per pen. Cattle waste, obtained daily from steers fed and housed on concrete, was diluted with water to provide a slurry containing approximately 7% DM (FI). Part of this slurry was mixed with the appropriate diet ingredients for feeding, while the remainder of the slurry was used to provide substrate for the anaerobic fermentor. The amount of FE or FI added to the appropriate diet was adjusted to provide the same amount of DM from either source. The diets containing FI and FE were mixed fresh daily. A diet with no supplemental soybean meal was used as a negative control, while the positive control diet contained supplemental soybean meal (Table 1). A 21-day period was allowed for adaptation to the diets and individual electronic headgates. After adaptation, liveweights were

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Table 1—Percentage composition[a] of diets fed to beef cattle (Experiments 1 and 2)

Item	Positive control	Negative control	Negative control + effluent	Negative control + influent
Experiment 1 (Steers)				
Ingredient composition				
Brome, smooth, hay	20.00	20.00	20.00	
Corn, yellow, grain, ground	72.00	79.00	72.55	
Soybean, seed, solvent-extracted ground	7.20	0	0	
Limestone, ground, mn 33% calcium	0.90	1.00	1.00	
Fermentor effluent (solids)	0	0	6.45	
Vitamins A, D, and E[b]	+	+	+	
Total	100.00	100.00	100.00	
Nutrient composition[c]				
Dry matter, %	44.0	44.0	38.1	
Crude protein, %	12.1	10.0	12.2	
Ash, %	5.7	5.4	7.1	
Neutral detergent fiber, %	31.4	35.0	32.3	
Cellulose	11.4	10.4	10.6	
Acid detergent fiber, %	16.2	13.9	15.5	
Lignin, %	2.9	2.6	3.1	
Gross energy, Mcal/lb	2.0	2.0	2.0	
Experiment 2 (Heifers)				
Ingredient composition				
Brome, smooth, hay	20.00	20.05	20.00	20.00
Corn, yellow, grain, ground	71.47	78.40	72.08	72.08
Soybean, seeds, solvent-extracted ground	7.10	0	0	0
Limestone, ground, mn 33% Ca	1.42	1.44	1.32	1.32
Calcium phosphate, dibasic, commercial	0	0.15	0.14	0.14
Solids from effluent	0	0	6.45	0
Solids from influent	0	0	0	6.45
Trace minerals	0.01	0.01	0.01	0.01
Total	100.00	100.00	100.00	100.00
Nutrient composition				
Dry matter	85.4	85.2	37.4	50.9
Crude protein[a]	11.4	10.0	12.2	11.3
Ash[a]	4.3	3.9	5.9	5.3
Ca[a]	0.28	0.28	0.60	0.50
P[a]	0.30	0.27	0.34	0.33

[a]Expressed on dry matter basis.
[b]Added to provide 2,200 IU vitamin A, 219 IU vitamin D_3 and .1 IU vitamin E/lb of dry ration.
[c]Values based on laboratory determinations. Expressed on dry matter basis except for dry matter.

taken on two consecutive days and then at 21-day intervals. Daily samples of each diet were obtained and composited over each 21-day weigh period. Feed not consumed was weighed and sampled for nutrient analysis every week. The experiment ran for a total of 126 days.

Results

Chemical Analyses. DM, ash, nitrogen (N), and total volatile acids (TVA) composition of the FI and FE are presented in Table 2. Because water is added to the raw waste before pumping into the fermentor, DM content of the FI is a reflection of the amount of water added. The 48.6% decrease in DM due to the fermentation process is similar to that observed previously. Total N and ash contents (g liter^{-1}) of the FI and FE were not different. However, if expressed on a DM basis, N and ash content increased due to reduction in DM during fermentation. Assuming that all nonammonia-N is in the form of protein, the protein content, expressed as a percentage of DM, is enriched from approximately 20% to 26% during the fermentation process. Ammonia-N concentration as a percentage of the total N increased from 24.9% to 46.3%. TVA concentration in FE decreased when expressed on both a DM basis and g liter^{-1} basis compared with FI.

Gross energy content of DM is not different between FI and FE (Table 2). However, energy that is available to the animal is undoubtedly less in FE compared with material in FI. FE contained a higher percentage of acid detergent fiber (ADF; lignocellulose) and lignin than FI (Table 4). Thus, material remaining in FE represents a more highly lignified, less digestible material than in FI. The material isolated following centrifugation (DCB) represents one of the least digestible FE fractions. The lignin and ADF content was more than double, and gross energy content lower, in DCB than in FE (Table 2). Thus, centrifugation yields a product that is chemically less desirable as a nutritional supplement than the complete FE.

Data in Table 2 indicate that loss of some N occurs during centrifugation and drying of FE. In wet centrifuged biomass, about 50% of the total N is recovered. During the drying process, more N is lost, primarily as NH_3-N (ammonia nitrogen), so that total N recovery after centrifugation and drying is about 40%. The conditions

Table 2—Composition of fermentor influent and effluent and dried centrifuged biomass

Component	Fermentor influent (FI)	Fermentor effluent (FE)	Dried centrifuged biomass
Dry matter[a], %	9.83[c]	5.05[b]	23.1
Ash, %[e]	0.26	.23	26.8
Cell contents[e]	58.6[c]	60.0[c]	21.2[b]
Cell walls (NDF)[e]	41.5[b]	40.1[b]	78.8[c]
Cellulose[e]	10.5[b]	10.6[b]	22.6[c]
Acid detergent fiber[e]	15.3[b]	20.0[c]	46.2[d]
Lignin[e]	3.1[b]	6.4[c]	13.4[d]
Gross energy (kcal/lb)	2.12	2.12[c]	1.81[b]
Total N			
lb N/cu ft[a]	0.26	0.24	---
lb N/lb dry matter (wet) x 1000	---	76.6	39.2
(after drying) x 1000	---	---	29.6
Ammonia-N			
lb/cu ft[a]	0.06[b]	0.11[c]	---
% of total N[a]	24.9	46.3	15.6
lb/lb dry matter x 1000	---	35.4	6.1
Total volatile acids (TVA)			
lb/cu ft	0.47[c]	0.15[b]	---
lb/lb dry matter x 1000	76.8[c]	46.4[b]	---

[a]Determinations made three times weekly during the 32-week experimental period except for centrifuged biomass. Fermentor retention time was 12 days. Effluent was used in a cattle feeding experiment during this period.
[bcd]Means without a common superscript differ ($p < .05$).
[e]Expressed as % of dry matter.

used in obtaining these data were controlled more than would be the case under practical conditions. Under some conditions, total N recoveries obtained were as low as 12 to 20%. This low recovery of N is of major concern because one objective of this research is to recover a high-protein livestock feed supplement.

Experiment 1. Weight gain, feed intake, and feed efficiency data are presented in Table 3. Steers fed the FE-containing diet had a 4% to 12% higher DM intake but gained wt about 15% slower than steers fed the negative or positive control diets. Feed efficiency (DM:gain) decreased by 17% to 25% in the FE-fed steers, compared to the control groups.

Performance of the steers fed the negative control diet containing 10% crude protein was somewhat surprising, considering the relative light wt (640 lb) at which steers were started on the experimental treatments. Protein requirements for this wt of cattle would be expected to exceed that provided by a 10% crude protein diet. However, the somewhat lower performance of all cattle in this experiment (less than 2.2 lb/head/day) may partially explain the apparently lower protein requirement of the steers used in this experiment.

The diets fed in Experiment 1 did not alter any of the carcass quality measurements (Table 3), although hot carcass wt was lower in steers fed FE. All steers had a quality grade in the high-Good or low-Choice range. Taste panel evaluations revealed that steaks from steers fed the FE diet were not different ($P > .05$) from steaks from steers fed the control diet. Thus, feeding of FE does not appear to have any detrimental effects on the eating qualities of steaks.

Experiment 2. Weights, gains, feed intake, and efficiency data for heifers are presented in Table 4. Period or cumulative ADG were not altered by dietary treatments. In contrast to the previous experiment in steers, feeding FE did not alter ADG or feed efficiency ($P > .05$). DM intake was also not altered by feeding FE or FI. Crude protein intakes were highest in heifers fed the FE, which is a reflection of the slightly higher crude protein content of the FE diet (12.2%), compared with the positive control diet (11.4%). Performance of heifers fed the negative control was similar to heifers fed the positive control diet which contained a soybean meal supplement. Similar performance of these two groups might be expected because the initial wt at the start of the experiment was approximately 827 lb, and a diet containing 10% crude protein should not be limiting for this size of animal.

Reasons for the differences in animal response to dietary FE between Experiments 1 and 2 are not clear. Differences between the two experiments included: 1) sex of animal, and 2) wt at the start of the experiment. It is doubtful that there would be a sex by diet interaction, but differences in initial wt might explain some of the differences, in that heavier animals may adapt more readily to FE.

No differences in performance were observed between heifers fed FI *vs* FE, even though relatively large differences existed between some components of the influent and effluent (Table 2). The amount of TVA decreased, and the percentage of total N present as ammonia increased in FE, compared with FI. However, in terms of total diet DM, these changes would be relatively small because FI or FE provided only about 6.5% of total diet DM (Table 1).

Building location and/or method of feeding did not alter feed intake, feed efficiency, or ADG in Experiment 2 ($P > .05$; data not presented). Thus, similar performance of cattle can be expected, whether they are fed individually using electronic headgates, or in a small-group feeding situation.

As observed in Experiment 1, feeding of FI or FE did not significantly alter carcass quality characteristics. Heifers fed FE and FI were lighter in wt initially and at slaughter than the positive or negative control heifers. The dressing percentage at slaughter was also slightly lower in FE and FI-fed cattle than in controls.

General Conclusions. Because of a limitation in the amount of material available, we have not been able to complete any long-term feeding experiments with dried centrifuged biomass (DCB) used in metabolism studies.

Table 3—Influence of protein level and fermentor effluent on liveweight gain, final wt, feed efficiency, and carcass quality characteristics of steers (Experiment 1)[a]

Item	Control	Negative control	Negative control + effluent
No. of animals	9	10	10
Initial wt[j], lb	663	636	621
Final wt[j], lb	1,013	993	923
Avg daily gain, (lb/head/day)	2.05	2.07	1.76
Adj avg daily gain[j] (lb/head/day)	2.09	1.98	1.72
Dry matter intake, (lb/head/day)	18.1	16.7	18.9
Protein intake, (lb/head/day)	2.16	1.65	2.33
Protein/gain	1.03[g]	0.77[f]	1.27[h]
Dry matter/gain	8.64[f]	7.86[f]	10.37[g]
Hot carcass wt, lb	605.3[e]	592.4[de]	541.3[d]
Dressing %[i]	59.9	58.2	58.8
Marbling[ik]	13.3	10.6	10.3
Quality grade[il]	10.9	9.3	9.2
Adj. fat thickness[i], in	0.57	0.41	0.40
Longissimus area[i], in^2	10.2	10.6	9.9
Kidney, pelvic fat[i], %	3.6	3.4	3.0
Yield grade[i]	3.7	3.0	3.0

[a]Means of nine or ten observations/treatment.
[bc]Means with different superscripts differ ($P < .10$).
[de]Means with different superscripts differ ($P < .05$).
[fgh]Means with different superscripts differ ($P < .005$).
[i]Differences in treatment means are not significant ($P < .05$).
[j]Adjusted to common dressing percentage.
[k]Marbling score: Slight = 7, 8, 9; Small = 10, 11, 12.
[l]Quality grade score: Good = 7, 8, 9; Choice = 10, 11, 12.

Table 4—Influence of diet on liveweights, avg daily gains, feed intake, feed efficiency, and carcass characteristics of heifers[a]

	Dietary treatments			
	Control	Negative control	Effluent	Influent
Initial wt[f]	870.1	854.7	803.3	801.5
Cumulative				
ADG[f], lb	2.65	2.82	2.80	2.82
Dry matter intake[df] (lb/head/day)	26.2	26.0	23.4	24.0
Crude protein intake[d]	3.5	3.1	7.9	5.3
Dry matter/gain[f]	9.4	8.9	8.2	8.1
Protein/gain	1.3[b]	1.0[b]	2.8[d]	1.8[c]
Hot carcass wt (lb)	665.5[c]	659.5[c]	622.7[b]	622.0[b]
Dressing percentage, %	61.1[c]	60.3[bc]	59.9[b]	59.9[b]
Marbling[ef]	8.6	9.0	8.9	7.4
Quality grade[ef]	8.3	8.4	8.1	7.4
Adj. fat thickness[f], in	0.35	0.31	0.31	0.30
Kidney, pelvic fat[f], %	2.7	2.9	2.5	2.5
Longissimus area[f], in^2	12.8	12.5	12.4	12.1

[a]Means based on twenty observations.
[bc]Means with different superscripts differ ($P < .05$).
[d]Lb per head per day.
[e]Marbling score: Slight = 7, 8, 9; Small = 10, 11, 12.
Quality grade score: Good = 7, 8, 9; Choice = 10, 11, 12.
[f]Differences in means are not significant ($P < .05$).

However, in other laboratories, an increased feed requirement per unit of gain and decreased gains in steers fed DCB-containing diets (10.5% of diet DM) has been observed. Because of the relatively high fiber and low digestibility of DCB, utilization of DCB may have to be restricted to maintenance-type diets. The major disadvantage of attempting to utilize the DCB is the amount of nutrients lost during the centrifugation and drying process. Mixing FE with dry diet overcomes the problem of nutrient loss, but new problems are introduced. The amount of DM from the FE that can be used in the diet is limited by the amount of liquid that can be added to the dry diet to obtain a final product that is approximately 35% DM. The maximum DM that we could add to the diet from the FE was approximately 5% to 7% of the diet DM. This level of biomass DM would not be expected to affect performance; however, in the first experiment with steers, a 15% decrease in performance was observed, although this was not observed in the second experiment with heifers.